Operation Everest II: Lack of an Effect of Extreme Altitude on Visual Contrast Sensitivity

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Contrast sensitivity thresholds were studied over 40 d during gradual ascent to a simulated terrestrial altitude of 25,000 ft in a decompression chamber. Only ambient pressure, and thus inspired oxygen pressure, was varied, thereby eliminating many of the confounding effects of cold, dehydration, malnutrition and exhaustion, inevitably encountered on very high mountains. Contrast sensitivity thresholds measured by the Ginsburg Vistech test showed no overall impairment as altitude increased. These results are different from those of other previously reported vision studies involving shorter exposures, lower altitudes, and lower test luminances. However, our results can be explained on the basis of the higher stimulus luminances used in our contrast sensitivity testing. Compared to the luminance levels involved in previously reported testing, our higher luminance stimuli would be less likely to be affected by hypoxia.

ONE OF THE FUNDAMENTAL attributes of visual experience is the perception of differences in stimulus luminance or contrast. The ability to detect these differences is fundamental to all functional vision since, except for color contrast and relative motion, objects are visible only when they differ in luminance from the background against which they are seen.

Visual acuity is universally regarded as the traditional threshold index of clear vision (2), and is based fundamentally on the detection of luminance contrast between figure and background. However, as conventionally measured, acuity involves only the response to black-white contrast at high levels of illumination. Consequently, the more sensitive detection of shades of gray is not measured by conventional visual acuity tests. Attempts to measure visual resolution along a wide range of stimulus luminances have led to the development of contrast sensitivity tests (1,4–6). In these tests, the subject is required to detect differences in brightness contrast at various spatial frequencies, measured in cycles of light and dark grating lines per degree of visual angle subtended at the retina (c/d). Contrast is defined as $(L_{max} - L_{min})/(L_{max} + L_{min})$, in which L_{max} is the highest luminance and L_{min} is the lowest luminance of the light and dark lines, respectively (11). The reciprocal of the contrast represented in a range of spatial frequencies is typically plotted as a contrast sensitivity function (15).

Many earlier studies have shown that visual performance tasks which depend on detection of light intensity and on discrimination of differences in intensity are adversely affected by hypoxia (16). Specifically, dark adaptation is rapidly impaired above 10,000 ft (10,11,13). Other visual tasks which depend on brightness detection have also shown impairment under hypoxia (8–10). Since contrast sensitivity is fundamentally a response to aspects of luminance levels, one might logically expect it also to be especially affected by hypoxia.

A recent project titled "Operation Everest II" (OE II) provided an opportunity to study the effects of prolonged exposures to extreme altitudes in a hypobaric chamber on contrast sensitivity, as part of a larger study involving various other medical, physiological, and psychological aspects of human performance. The purpose of this project was to examine many aspects of acclimatization to hypobaric hypoxia under controlled conditions. The rate of ascent and altitudes reached were patterned after those of major Himalayan expeditions to Mount Everest (17). However, aspects of cold, dehydration, malnutrition, and fatigue were

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notably absent, since the chamber was kept at comfortable conditions and the subjects were given ample food, fluids, rest, and the opportunity to exercise at will. The project, thus, was a study of the effects of "pure hypoxia," and was not a simulated mountain ascent. See Houston (7) for a detailed account of the OE II project.

This paper is concerned only with measurements of contrast sensitivity which were obtained periodically throughout the course of exposure; the results of other tests conducted during the study are reported elsewhere.

MATERIALS AND METHODS

Eight male subjects and one alternate were selected from a large pool of applicants on the basis of their ages (21–31 years), motivation, physical fitness, and interest in human physiology. After intensive medical screening and a flight physical examination, they were given 5 d of training and base-line testing on all of the experimental tasks at sea level. They were then briefed about the details of the study and signed an informed consent agreement prior to participation. They were also instructed in emergency procedures within the chamber. The schedule of altitudes employed is listed in Table I, and is shown graphically in Fig. 1.

Two subjects were removed from the chamber at 18,000 and 25,000 ft, respectively, because of hypoxic episodes from which they recovered immediately. The remaining six subjects completed 40 d of ascent. Because of headache and insomnia above 20,000 ft, the simulated altitude was decreased by 1,000 to 1,500 ft at night, thus following the mountaineers' practice of "working high and sleeping low." On the 41st day of exposure, the chamber was rapidly returned to sea-level, and the six subjects who completed the entire study underwent follow-up testing and debriefing during the next 2 d.

The contrast sensitivity measures were obtained by use of the Vistech test (4), using the hand-held technique of administration. In this version of the test, the subject views a display containing five rows of circular test targets mounted on a 5-in. × 7-in. plastic card. This card is viewed in a plastic template held against the face, which positions the card in direct line of sight and at a fixed 18-in. viewing distance. The rows on the card (labeled A through E) represent five different spatial frequencies (1.5, 3, 6, 12 and 18 c/d), and each row contains nine targets representing a threshold sequence of increasing contrast sensitivity for that spatial frequency. The array of contrast sensitivity levels versus spatial frequencies contained on the card is summarized in Table II.

The light and dark grating lines contained in the targets are intentionally tilted to the right, tilted to the left, or oriented vertically to control for guessing. Each row on the card consists of a different randomized order of right-tilt, left-tilt and vertical targets. The ninth target of each row is homogeneous gray, and is intended to serve as a test of no-response. The subject's task is to indicate the apparent direction of tilt of each of the targets successively in sequence along each row. The highest numbered target in each row for which stripes are still visible is considered the limit threshold for that row.

Three equivalent forms of the test card, each having a different order of grating orientations, were alternated daily in this study in randomized order to minimize possible learning effects. Because of restrictions due to operation of the chamber and the extreme altitudes involved, it was necessary for the subjects to self-administer the test, and to

TABLE I. DAILY SEQUENCE OF ALTITUDE CONDITIONS.

Test Day	Cont. Sens. Tests	Daytime Altitude feet	Daytime Altitude meters	Baro. Press. (mm Hg)	Nighttime Altitude feet	Nighttime Altitude meters	Baro. Press. (mm Hg)
1	****	4,000	1,219	656			
2		7,500	2,286	576			
3		10,000	3,048	523			
4	****	11,000	3,353	503			
5		12,000	3,658	483			
6		13,000	3,962	464			
7		14,000	4,267	447			
8	**\	15,000	4,572	429			
9	**/	15,000	4,572	429			
10		15,000	4,572	429			
11		15,000	4,572	429			
12		16,000	4,877	412			
13		17,000	5,182	396			
14		18,000	5,486	380			
15		18,000	5,486	380			
16	****	18,000	5,486	380			
17		19,000	5,791	364			
18		20,000	6,096	347			
19		20,000	6,096	347			
20		20,000	6,096	347	18,000	5,486	380
21		18,000	5,486	380	18,000	5,486	380
22		20,000	6,096	347	19,000	5,791	364
23	****	20,000	6,096	347	20,000	6,096	347
24		20,000	6,096	347	20,000	6,096	347
25	****	20,500	6,248	342	20,500	6,248	342
26		22,000	6,706	320	21,500	6,553	328
27		23,000	7,010	308	22,000	6,706	320
28	****	23,000	7,010	308	22,500	6,858	314
29		23,500	7,163	301	20,000	6,096	347
30		24,000	7,315	295	21,000	6,401	335
31		24,500	7,468	289	22,500	6,858	314
32	****	25,000	7,620	282	22,500	6,858	314
33		25,000	7,620	282	22,500	6,858	314
34		25,000	7,620	282	22,500	6,858	314
35		25,000	7,620	282	23,500	7,163	301
36		25,000	7,620	282	24,000	7,315	294
37		25,000	7,620	282	22,500	6,858	314
38		25,000	7,620	282	22,500	6,858	314
39	****	25,000	7,620	282	22,500	6,858	314
40		25,000	7,620	282	22,500	6,858	314

Note: Half of the subjects were tested on Days 8 and 9 each, due to administrative problems.

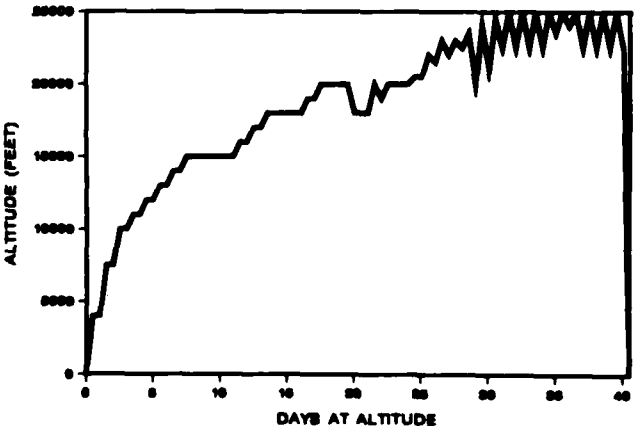

Fig. 1. Profile of the daily sequence of altitude exposure conditions.

TABLE II. SPATIAL FREQUENCIES AND CONTRAST SENSITIVITIES OF THE TEST STIMULUS TARGETS.

Test Row	Spatial Frequency	Test Target Number								
		1	2	3	4	5	6	7	8	9
A	1.5	11	22	30	40	53	71	95	126	BLANK
B	3	17	31	41	55	73	98	130	174	BLANK
C	6	20	41	54	72	96	128	171	230	BLANK
D	12	13	25	39	52	70	93	125	168	BLANK
E	18	8	12	16	22	30	40	53	71	BLANK

call out their answers ("right", "left", "straight", "blank") over the intercom to a technician outside the chamber who recorded the data. All subjects performed the test once daily between approximately 1500–1700 hours, on the days indicated by asterisks in Table I. The ambient illumination level within the chamber was virtually identical for all test sessions, and was found to fall within the normal range recommended for correct administration of the Vistech test.

RESULTS

For scoring purposes, the records of all subjects for all test sessions were evaluated using a performance criterion of the highest-numbered contrast sensitivity target correctly identified at each spatial frequency. These scores were first converted to their equivalent contrast sensitivity values and then were collated for each subject in each test session. The resulting database was used for analysis of the results. In order to retain the maximum possible hypoxia data for analysis, the appropriate group mean values for the subjects were substituted for missing data caused by required removal of the two subjects from the chamber at 18,000 ft and 25,000 ft, respectively. Compared to the alternative of excluding these two subjects from the database entirely, this procedure allowed us to retain maximum data for all subjects under the exposure conditions which they completed. We considered this option to be a legitimate compromise which was based on the prevailing group mean values, and which arithmetically gave the same numerical group mean values as those for subjects who completed the exposure conditions. Without these substitutions, the computerized statistical programs used in the analyses could not have been conducted, since they require complete data blocks in order to run.

In order to identify and interpret the changes in contrast sensitivity which may have occurred during the course of exposure to the sequence of altitudes, an overall subjects × treatments analysis of variance for repeated measures was first performed based on the individual contrast sensitivity scores for each spatial frequency for each subject across the daily test sessions indicated by asterisks in Table I. This analysis was performed by means of Program 2V of the Biomedical Data Programs (BMDP) library (3). The results indicated a significant main effect attributable to the different spatial frequencies (F) involved in the test ($F = 226.55$; $df = 4,24$; $p < 0.0001$). None of the other main effects or associated first-order interactions approached significance. The daily group means of the contrast sensitivity scores are plotted in Fig. 2 as separate curves for the respective spatial frequencies. It is clear that the highest contrast sensitivities were obtained for the midrange spatial frequencies (i.e., 3, 6, 12), while lesser values occurred for the low and high

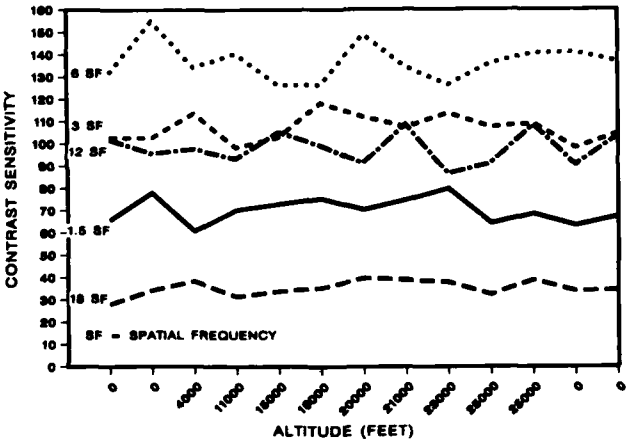

Fig. 2. Daily group means of contrast sensitivity for each spatial frequency.

spatial frequencies (i.e., 1.5 and 18). This differential effect has been reported in the literature as characteristic of response to spatial frequency in general, notably by Sekuler, *et al.* (14), who have referred to this phenomenon as the "window of visibility."

From these results, it appears that the Vistech contrast sensitivity test was sufficiently sensitive to detect differential reactions of the subjects to separate spatial frequencies. However, the effects of increasing altitude exposure were apparently not strong enough to impair overall judgments of contrast sensitivity. These results are in contrast to other reports in the literature on impaired night vision and brightness discrimination during acute exposures to much lower altitudes.

In order to determine whether altitude exposure might have differentially influenced contrast sensitivity for certain but perhaps not all spatial frequencies, the same data were then divided into five sub-sets, each corresponding to one of the five spatial frequencies involved in the Vistech test (1.5, 3, 6, 12 and 18 cycles/degree). A separate BMDP2V analysis of variance was then conducted on each of these data sets. The only significant main effects obtained in any of the five analyses were those attributable to subjects ($p < 0.001$). These results indicated again that altitude exposure had neither an overall effect on contrast sensitivity, nor separate effects within the respective spatial frequency ranges.

Despite these findings, significant trends might still be present within the individual data, which could have been masked by the pooling processes inherent in analysis of variance techniques. In order to investigate this possibility, the contrast sensitivity values for all subjects were tallied overall and then combined in two separate counts reflecting each of the two basic dimensions of the study design (altitude combined across all spatial frequencies, and spatial frequency combined across all altitudes). These frequency counts are summarized in Table III (altitude count) and Table IV (spatial frequency count).

Frequency histograms of the respective arrays were then plotted, and are displayed in Fig. 3 for the spatial frequency counts, and in Fig. 4a and 4b for the altitude counts. An inspection of these histograms indicates a generally close correspondence among the distributions of scores for the various test targets, in that the majority of higher counts

TABLE III. GROUP TOTALS OF TEST TARGETS RESOLVED FOR EACH SPATIAL FREQUENCY COMBINED ACROSS ALL ALTITUDES.

Test Target	Spatial Frequency (cycles per degree)				
	1.5	3	6	12	18
1					1
2					
3					1
4	1	1	4		17
5	34	11	9	11	29
6	38	69	69	70	46
7	21	19	20	17	5
8	8	5	3	4	6

TABLE IV. GROUP TOTALS OF TEST TARGETS RESOLVED FOR EACH ALTITUDE COMBINED ACROSS ALL SPATIAL FREQUENCIES.

Test Target	Altitude (ft)					
	0000	4,000	11,000	15,000	18,000	20,000
1			1			
2						
3						
4	3	7	1		1	3
5	15	9	7	7	9	12
6	40	25	31	38	20	25
7	20	4	5			5
8	12					

	21,000	23,000	25,000	25,000	0000	Sum
1						1
2						
3	1					1
4	7		1			23
5	6	12	16	17	39	29
6	15	8	12	3	10	82
7	6	3	1		4	26
8						

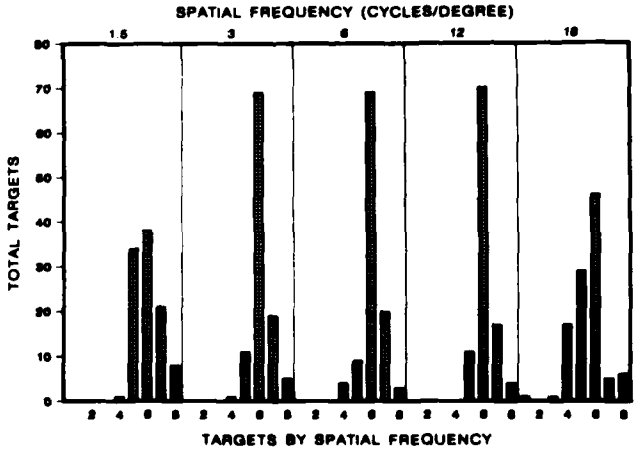

Fig. 3. Frequency histograms of overall targets chosen for each spatial frequency combined across all altitude conditions.

occurred for the normal- to high-normal range of contrast sensitivity values. This was true both for the overall range of altitude conditions (Fig. 3), and over the range of spatial frequencies (Fig. 4a and 4b). These results indicate clearly that the thresholds of resolution remained at typical to somewhat high levels of sensitivity over the course of the study, and resembled those obtained in base-line testing.

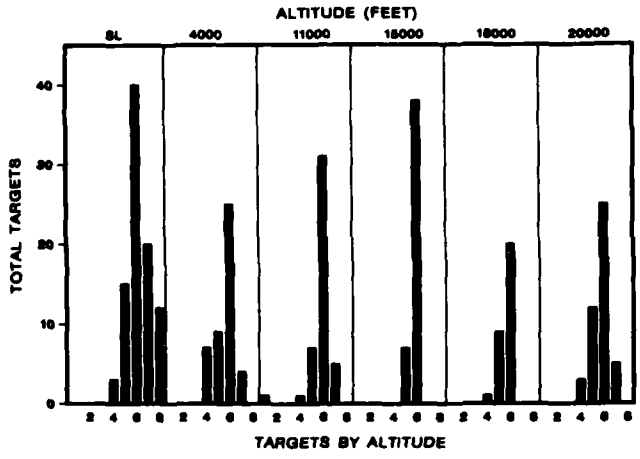

Fig. 4a. Frequency histograms of overall targets chosen for each altitude condition combined across all spatial frequencies.

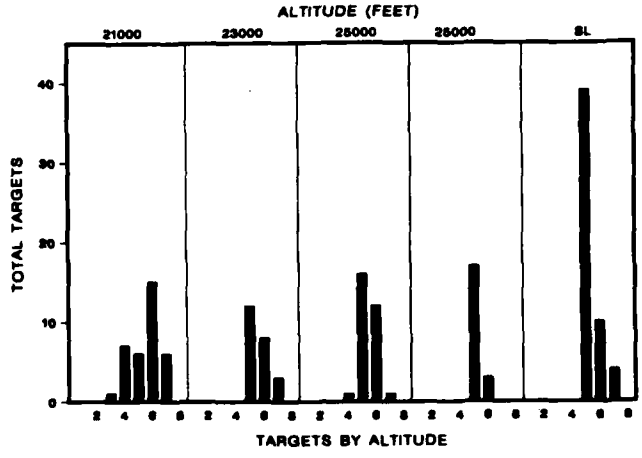

Fig. 4b. Frequency histograms of overall targets chosen for each altitude condition combined across all spatial frequencies (continued).

The lower overall totals in Fig. 4a and 4b for altitudes from 18,000–25,000 ft are attributable to the removal of two subjects from the chamber at 18,000 ft for medical reasons. This reduced the number of responding subjects by one-third, and thus the target totals shown in the figures. The subsequent increase in targets at the final sea level testing appears to be due to a redistribution of target choices primarily to the middle target.

As a final check on the individual distributions of threshold scores, the contrast sensitivity values for the various spatial frequencies were profiled separately for each daily session for each subject, using a standard form supplied with the Vistech test. A visual inspection of these profiles revealed a high consistency within the separate sets of curves for respective subjects, and indicated that they retained a remarkable continuity in their performances. Also, the performances of the individual subjects all were highly similar; in fact, the graphic profiles were scarcely discernible from each other. All of the individual profiles showed a clear overall trend of higher contrast sensitivity for the mid-spatial frequencies, and lower sensitivity for the low and high spatial frequencies, which mirrored the trends in the overall data evident in Fig. 2.

DISCUSSION

The results indicate clearly and consistently that contrast sensitivity was affected only slightly, if at all, by the hypoxic conditions of this study. Our data do not agree with previous reports of impaired night vision at moderate altitude (8–10, 12). One explanation may be that the subjects were acclimatized in this study, whereas the previous night vision studies were done on unacclimatized subjects acutely exposed to mild hypoxia. Another possibility is that night vision and contrast sensitivity are distinctly but subtly different, resulting in a segmented or differential hypoxia effect on the visual response to stimulus luminance. If this is true, then low scotopic stimulus levels would logically be more affected by hypoxia than would higher mesopic and photopic stimulus levels. The much lower stimulus energy of scotopic stimuli would fall below a minimum threshold of excitation for retinal photoreceptors due to the conditions of reduced oxygen and lowered atmospheric pressure. Mesopic and photopic stimulus levels, on the other hand, would be above this threshold, and therefore might not be affected. By this reasoning, the faint near-threshold stimuli involved in dark adaptation testing should be more vulnerable to hypoxia than should those at the much higher luminance levels employed in contrast sensitivity tests. This seems a reasonable argument, but one still must consider the severity of the extreme altitudes and extended exposure conditions involved in this study. The conditions used here have rarely been employed in other altitude research involving visual tasks.

It may also be possible that the particular manner in which this study was conducted affected the contrast sensitivity results obtained, or that the choice of subjects and/or the small number of subjects tested were insufficient to distinguish the effects of altitude. However, the high comparability of performance among the subjects would argue against this latter point.

It is unfortunate that practical limitations prevented obtaining both dark adaptation profiles and contrast sensitivity data on the subjects through the course of the study, and so a definitive test of the proposed explanation of the disagreement of our results with those of previous literature cannot be reached on the basis of the present data.

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The views, opinions and/or findings contained in this report are those of the author(s), and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other official documentation.

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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